passing through a tube of lime as in (fig. 3). It is our intention to try a combination of the electric arc and induction spark in these crucibles. It is hardly necessary to note that the projection of the reversals of the lines of metallic vapours may be effected by this method better than by any method heretofore in use.

February 27, 1879.

THE PRESIDENT in the Chair.

The Presents received were laid on the table, and thanks ordered for them.

Major-General Thuillier (elected 1869) was admitted into the Society.

The following Papers were read:—

I. "Studies in Acoustics. I. On the Synthetic Examination of Vowel Sounds." By WILLIAM HENRY PREECE and AUGUSTUS STROH. Communicated by the PRESIDENT. Received February 17, 1879.

[PLATES 6, 7.]

1. The authors of this paper have devoted much time during the past twelve months to a study of sonorous vibrations and the reproduction of speech. The invention of the phonograph has proved a great stimulus to this study. Many have worked in the same field, and many of the facts elicited by the authors have been anticipated by those who have been able to give more continuous study to the subject. Nevertheless, the mode of enquiry, the apparatus employed, and the results obtained are thought to be of sufficient novelty to justify their being brought before the Royal Society.

2. The curves traced by the vibrating disk of the phonograph on tinfoil, whether examined microscopically or reproduced by a species of pantelograph, were soon found to be insufficiently delicate to give the nicer shades of sound, and to fail to indicate the true curve of vibrations in all cases. This is shown by the imperfect reproduction of speech by the phonograph itself; the merging of the labial and dental sounds into one another, and the absence of all the sibilants and generally of the "noises" of speech. The phonograph is in reality a very imperfect speaker, and it requires the aid of much imagination and considerable guessing to follow its reproductions. It produces

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music with wonderful perfection, but it fails to reproduce most of the "noises" of which speech is so largely made up. The telephone is also deficient in this respect, though to a much less degree.

3. The first object of the authors was to find a disk which would vibrate to the finest shades of sonorous vibrations, and which would be free from those characteristic and "personal" partials which are nearly inseparable from all vibrating disks, and which interfere with their true action. After innumerable experiments, on almost all known forms and substances, a stretched membrane of thin india-rubber rendered rigid by a cone of paper, was found to give the best effects. Such a disk was applied to the telephone and the phonograph with fair results, and the apparatus shown in fig. 1 was then constructed to record its vibrations. To the centre of the cone *ab*, shown in perspective and section in fig. 1, which was placed in a mouthpiece similar to that of a phonograph, was attached an extremely fine glass tube (*g*), which acted as a pen. The ink employed was aniline dye, and it was drawn through the pen by the very slight friction exerted between its point and the paper. The paper (*p*) on which the curves were to be drawn was the broad band frequently used for telegraphic purposes, and it was moved under the pen by mechanism similar to that used in the Wheatstone automatic telegraph apparatus, at a speed which could be varied at will from 1 to 18 inches per second.

4. In this way curves were obtained illustrating the sonorous vibrations due to the tones of speech, but their form was not so perfect as could have been wished, due to the imperfections of the disk, as well as, perhaps, to the friction of the pen failing to indicate the higher upper partials. Run at a slow speed, this instrument records the variations of air pressure in front of the lips; run at a high speed it records both air pressure and sonorous vibrations. It thus combines the functions of Barlow's logograph and Leon Scott's phonautograph.

5. It is intended, in this paper, to confine our observations to those facts illustrating vowel sounds, a graphic representation of which, drawn by the new phonautograph, is given in the following sketch (fig. 2).

6. Helmholtz's theory of vowel sounds is this:—Vowels are compound musical tones, or resultant sounds formed by the combination of certain components or simple tones called partials. The first partial, which determines the pitch of the whole, is called the prime, and the others its upper partials. The partials depend upon the reinforcements due to the cavity of the mouth. Vowels do not depend upon the pitch of the prime alone, or on the grouping or harmony of the partials alone, but on both. The ear must distinguish each component; it must recognise the kind of cavity producing the reinforcements, and therefore it determines the different vowels. This theory has been partly

confirmed recently by Messrs. Fleeming Jenkin and Ewing, by an analytical examination of phonographic tracings, fully described by them in a paper read before the Royal Society of Edinburgh.

7. The principal vowel sounds are—

Ah,	as in	..	..	..	path
A	,,	..	..	..	hay
E	,,	..	..	..	he
O	,,	..	..	..	old
oo	,,	..	..	..	good.

There are several others which are modifications of these five, such as *uh* as in gut; *ă* as in bad; *aw* as in law, &c.

The diphthongs are :—

i	which is	compounded of	ah and e.
u	,,	,,	e and oo.
y	,,	,,	oo, ah, and e.

8. The cavity of the mouth changes during the articulation of these diphthongs—it remains constant during the articulation of vowels. It is thought that the influence of the first emission of breath in distinguishing the character of the vowels has been lost sight of, and that in addition to the influence of the cavity of the mouth, some allowance must be made for the increment and decrement of the sonorous vibrations, as well as for the variation of air pressure at the commencement and completion of a vowel sound. Helmholtz has acknowledged the influence of these operations in consonants and compound musical tones generally, but he has not considered them in vowel sounds. The previous diagram (fig. 2) shows what an essential feature they bear on vowel sounds.

9. The manner in which vowel sounds blend into each other is strikingly shown in the way in which different dialects deal with different vowels. Thus, what a London man calls *subject* a Lancashire man calls *soobject;* a Londoner says *Măncheste*r, a Lancashire man *Mawnchester*, a Scotchman *Monchester*. *Under* is often pronounced *ŏnder*. We need not, however, examine different dialects to discover this curious blending of vowel sounds; it is found in inhabitants of the same district to a greater or less extent. Thus with the word *Manchester*, Londoners often say *Menchester*, *Manchester*, or *Marnchester*. In every case which the authors have investigated, this change of vowel sound, due to dialect, is simply due to the shifting or lowering of the upper partials.

10. The order of the principal vowels, which is given above, does not follow any theoretical principle. It would seem that a better order to follow would be one dependent on the *pitch* of the partials as given by Helmholtz.

1. ..... oo } uh—(gut).
2. ..... o } aw—(law).
3. ..... ah } ă —(bad).
4. ..... ā }
5. ..... e

All the subsidiary vowels, such as uh, aw, ă, take up intermediate positions in this scale, so that, in fact, we may say that there is a vowel spectrum, in which the different sounds merge into each other by almost imperceptible gradations, and hence, probably, the difference in dialectical pronunciation.

11. In the following investigation, a method opposite to that of Messrs. Fleeming Jenkin and Ewing has been adopted, *i.e.*, the question has been attacked by the method of synthesis. It has been assumed that vowels are compounded of a prime sound and certain upper partials, and the number of these partials has, for convenience, been taken as 8, although there are many more. Indeed, we have taken in some cases, the 10th, 12th, and 16th. Now, since each partial can be considered as a simple harmonic curve, if we assume the pitch of a prime to be constant, then it would be possible, by means of a machine, to represent and vary each partial in phase and in amplitude. For this purpose an instrument was constructed, which we call "the synthetic curve machine," in which a number of toothed wheels, A, B, C, D, E, F, G, H, &c. (figs. 3 and 4) are mounted on steel pins or axes rigidly fixed on a board, so that they will revolve together, and the numbers of their teeth are so calculated that during one revolution of the wheel A, B will make two, C three, D four, E five, F six, G seven, H eight revolutions, and so on. The wheel I has, on its prolonged axis, a small crank, by means of which the whole system of wheels can be rotated. On the same axis is a pinion I′, gearing into the wheel J, which, by means of a chain T, gives motion to a sliding table R. Each head of the pins on which the eight wheels revolve, has, in its centre, a small pit or hollow, in which rest the pointed ends of eight steel rods (one of which B′ only is represented in fig. 4), held in position by eight springs *b*. To the rod on the wheel A is attached, near its point, one end of a silken thread *b*′, passing over the roller N′, the other end being attached to the rod on wheel B. The rods on wheels C and D, E and F, G and H are similarly connected. The four rollers N are mounted on two levers U and U′, and these are connected by links to the lever V, which is finally linked to the lever P. This lever P is pivoted at *p*, and by means of the spiral spring S keeps the levers, links, and silk threads in a state of tension. On the longer end of the lever P is pivoted another lever O, which carries at its shorter end

a small counterbalancing weight (W), and at its longer end a glass pen (Q) containing suitable ink. On the table R is placed a piece of paper or smoked glass, which is held there by two spring clamps. Each of the eight wheels has on its face a number of small holes or pits, into which the points of the rods B′ can be placed, and these are arranged in eight rows radiating from the centre. When one of the rods, for instance that belonging to the wheel B, is placed in position B″, as indicated by the dotted lines, and motion is given to the wheels by means of the crank on the axle belonging to the wheel I, the crank-like movement of the rod B′ will, by means of the silk thread *b*′, roller N′, levers U, V, and O, cause the pen Q to move to and fro with simple harmonic motion, while the table R will move longitudinally, the pen thereby writing on the paper a simple harmonic curve. This can be done with each of the eight rods separately, the result being in each case a simple curve. Should, however, two or more rods be placed on the faces of the wheels, the result will be a curve compounded of the sum of the several simple curves. In order to increase or decrease the amplitude of a curve, the steel rods are placed further from, or nearer to, the centre of the wheels. Difference of phase is obtained by shifting the rods to the different radial rows of holes on the face of the wheels. Three additional wheels, K, L, M, have been fitted, making 10, 12 and 16 revolutions respectively, to one turn of the wheel A, and the rods belonging to neighbouring wheels are so arranged that they can be borrowed for the use of these smaller wheels if desirable.

12. Besides assuming the pitch to be constant, it has also been assumed that each octave of the partial, to maintain equal loudness of sound, must diminish one half in amplitude as it rises. Thus the

First Octave is	$\frac{1}{2}$	the amplitude of the prime.		
Second	,,	$\frac{1}{4}$	,,	,,
Third	,,	$\frac{1}{8}$	,,	,,
Fourth	,,	$\frac{1}{16}$	,,	,,

The intermediate notes, such as the third and the fifth, decrease in intermediate ratio.

13. This instrument enables us to form synthetically all the curves produced by vowel tones, and to show how these tones are compounded of primes and harmonic upper partials. It shows how *simple tones* can be produced by simple harmonic curves, and *compound tones* by the simultaneous action of several simple tones.

The following figure (fig. 5), shows the simple harmonic curve produced by each wheel, and several examples of curves formed by different components. In this way curves have been reproduced as shown in fig. 6, representing the vowel sounds based on Helmholtz's theory, as indicated by Mr. Ellis in a tabular statement, at page 181 of his translation of Helmholtz's work.

Figs. 7 and 7A show reproductions of the vowel *O*, sung at different pitches, as determined by Messrs. Fleeming Jenkin and Ewing.

14. [It is worth remarking parenthetically, that one interesting fact arising from the operation of this machine, was that curves could be so constructed as to give a stereoscopic effect. One curve was drawn simple, and the other, drawn in the same line—at the proper distance from it to fit a stereoscope—was made compound, by the addition of a partial of low amplitude. The result of the combination by the eye in a stereoscope of these two curves, was to produce a perspective effect. By this means curves have been drawn which interlace amongst each other, giving stereoscopic effects in a manner which is unique and interesting. This has no bearing whatever on the investigation, and is only adduced as a scientific toy arising out of the enquiry.]

15. Having thus studied the formation of vowel sounds, and having a means to reproduce the compound curves which graphically represent the motions which the air particles assume under their influence, the authors determined to try to reproduce these vowels by superimposing partials on to a given prime.

Since vowels are produced by a prime and its upper partials, and as the upper partials diminish so rapidly in amplitude, the idea arose that these vowels might be reproduced by sounding a prime and one of its partials alone. This was done by means of an electro-magnet E, fig. 8, vibrating an armature (A) with a moveable spring (S) attached to it in such a way that the vibrations of the armature could produce a given prime, while the vibrations of the spring, by varying its length, could also be adjusted to any particular partial.

16. The result was to roughly reproduce the principal vowel sounds, but the effect not being by any means perfect (due to the absence of the other upper partials), a machine was made on the principle of the synthetic curve machine, which would, instead of drawing curves on paper, reproduce eight partials by transferring the vibrations of the intermediate wheels to a vibrating diaphragm. This machine consists of eight wheels fixed on the same axis, the periphery of the wheels being cut into teeth of such a number as to represent the eight partials. Each tooth is a simple harmonic curve, and each wheel represents one partial. The axis can be rotated by a crank at any given velocity. By depressing a key a spring can be brought into contact with the edge of each wheel, and be thus vibrated. The vibrations of these springs are transferred by thin cords and intermediate linking to a diaphragm of ebonite. Each spring can be depressed separately or simultaneously with others, and the disk will vibrate to the resultant effect of all the vibrations. Thus, notes and chords can be sounded.

17. Here again, though the vowels were fairly reproduced, some-

thing was wanting in their clearness. This instrument proves to be an excellent syren, and all the facts illustrated by the apparatus of Cagniard de la Tour and others can be equally illustrated by it. Moreover, it forms the basis of a new musical instrument which there has been no time as yet to mature.

18. In the hope of getting more perfect definition, another machine was now made upon which disks were fitted, whose peripheries were cut in exact copy of the curve produced by the synthetic curve machine. These curves were transmitted by vibration to the receiving diaphragm of a phonograph, and really formed an "automatic phonograph." The automatic phonograph consists of an axle A, fig. 9, about 6 inches long, one end of which carries a fly-wheel B, and the other end a grooved pulley C, round which a band or gut passes from a driving wheel D, fitted with a crank handle E. On rotating the driving wheel, the long axle is caused to make about three revolutions to one of the wheel.

On the long axle are placed, in such a manner that they can easily be removed and replaced by others, a number of brass wheels or disks, a, a, a, a, the circumferences of which have been cut by a machine especially devised for that purpose into the different curves corresponding exactly to the curves obtained by the synthetic curve machine, but on a much reduced scale.

A diaphragm G with spring and frame H, similar to that in a phonograph, is so fitted that it can be shifted from one disk to another, and the sounds produced by the different curves can be readily compared. The number of periods or resultant vibrations recurring on each wheel or disk has for convenience been taken at thirty. Thus, when the driving wheel is rotated about twice per second, 180 to 200 vibrations are caused, resulting in a note at f or g in the musical scale.

A number of combinations of curves has been cut on the circumferences of the brass disks, representing each vowel sound with certain variations of the partials, as experience determined. These disks were then placed on the axle, and the sounds most resembling the vowel sounds of the human voice were easily recognised.

19. In this way it was found that from about f to b in the musical scale, the sound *oo* consists mainly of the first partial or prime. But to maintain the *oo* character descending the scale, the second and third partials became slightly necessary.

20. The prominent partial in the vowel sound *O* at the same pitch is the second, while the first can be reduced considerably. The third and fourth partials have to be used as the sound descends the scale, otherwise what is *O* at say b flat, will become *oo* an octave lower.

21. The vowel sound *ah* is the easiest to reproduce. It consists chiefly of the third, fourth, fifth, and sixth partials at the above pitch, the first and second partials being only slightly represented. A little

more prominence to the second, third, and fourth partials will result in *aw*, while a bright *ah* is obtained by increasing the amplitude of the fifth and sixth partials.

22. A very good and full *ah* is obtained by having all the partials equally represented, from the first to the eighth; and this really probably takes place when the human voice pronounces this vowel, as, in so doing, the mouth cavity is fully opened, so as to favour most of the partials.

23. The vowel sounds *ā* and *ee*, when reproduced by most of the ordinary phonographs, resemble respectively more *o* and *oo*. Also the curves for *a* and *ee*, obtained by the phonautograph, fig. 2, resemble those for *o* and *oo*. This shows, in the first instance, that neither instrument is sensitive to the higher upper partials; and, secondly, that the lower partials for *a* must be similar to those in *O*, and the lower partials for *ee* must be the same as in *oo*. To prove this, two disks were cut, one with a curve composed of the first, second, and eighth partials, and the other of the first, third, and eighth partials. The former, when sounded, produced a sound like *ee*, and the latter more like *a*.

24. The best *ee* has been obtained from a curve composed of the best first, second, eighth, and sixteenth partials; and *ā* from a curve composed of the first, third, and sixth or eighth partials; but this last curve can hardly be called satisfactory.

25. Diagram 10 graphically illustrates the above facts, and the following table gives them in a tabulated form:—

Vowels.	Partials with their Intensities.							
oo	1.	2.	3.					
	ff.	mf.	pp.					
ah	1.	2.	3.	4.				
	mf.	f.	mf.	p.				
o	1.	2.	3.	4.	5.	6.	8.	
	p.	p.	p.	mf.	mf.	p.	p.	
a	1.		3.				8.	
	mf.		mf.				ff.	
ee	1.	2.					8.	16.
	mf.	p.					p.	mf.

Hence, although the reproduction of vowels was good, it was imperfect. This is due probably to the absolute impossibility of reproducing the noises that accompany the last two vowels.

26. One very curious result arising from the experiments with the automatic phonograph was to show that, by varying the pitch, the vowel sounds could be shifted, *i.e.*, the curve which produced *oo* at a low velocity becomes approximately *O* at a higher velocity. *O* similarly becomes *ah*, *ah* becomes *ā*, and *ā*, *ēē*.

27. It follows from this investigation as far as it has gone, that our knowledge of vowel sounds is not perfect. The principal proof of this is the fact that vowels cannot be reproduced exactly by mechanical means. Something is always missing—probably the noises due to the rush of air through the teeth, and against the tongue and lips.

28. The curves (fig. 10) arrived at synthetically do not differ very materially from those arrived at analytically by Helmholtz (fig. 6). They principally differ in the prominence of the prime. But the prime can be dispensed with altogether. Curves produced by the synthetic machine, compounded of the different partials without their prime, show that there exist *beats* or resultant sounds. A vowel sound of the pitch of the prime may be produced by certain partials alone, without sounding the prime at all. The beat in fact becomes the prime. This point is clearly illustrated, orally, by the automatic phonograph, and graphically by the sketch (fig. 11), drawn by the synthetic curve machine. In fact, every two partials of numbers indivisible by any common multiple, if sounded alone, reproduce by their beats the prime itself. Thus, the third and the fifth partials, or the second and the third, &c., will result in the reproduction of the prime. In fact, fig. 11 illustrates not only this, but it shows that when the number of partials introduced is increased, the beats become more and more pronounced.

II.—*The Loudness of Sound.*

29. Another point remaining for investigation arising out of this inquiry, is the true theory of the loudness of sound. It is thought by the authors that loudness does not depend upon amplitude of vibration only, but also upon the quantity of air put into vibration; and, therefore, there exists an absolutely physical magnitude in acoustics analogous to that of quantity of electricity or quantity of heat, and which may be called the quantity of sound. This can be shown experimentally by constructing three disks like those in fig. 1, whose diameters increase in arithmetical ratio. When these disks are vibrated by the same curve by the automatic phonograph, or when they are thrown into vibration by tuning forks, it will be found that the intensity of sound increases in a surprising ratio. The amplitude remains just the same; the area under vibration alone increases. Thus, in the automatic phonograph, for two notes, one of which is an octave higher than the other, the area ought probably to be diminished one-half for the higher to produce equal loudness. Similarly for the same note, if we increase the area to be vibrated in its reproduction, it will be found that, as the area increases, so does the loudness of the sound emitted. In fact, in the automatic phonograph the diameter of the sounding disk ought, if it were possible, to vary with the pitch of each note, to produce equal intensity of sound.

Preece & Stroh

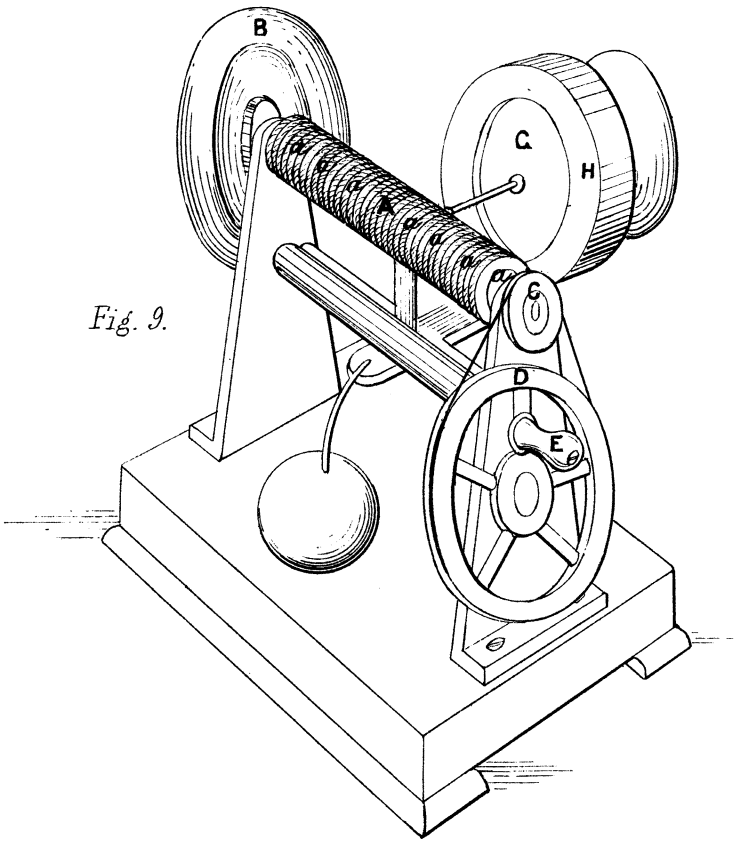


Fig. 9.

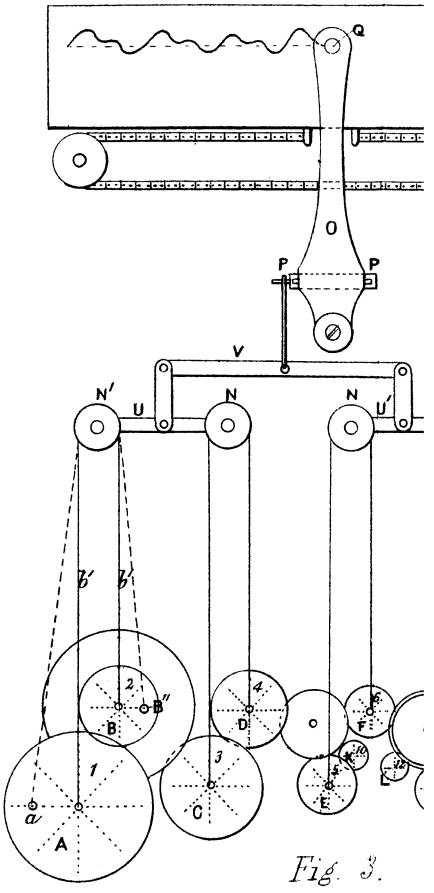
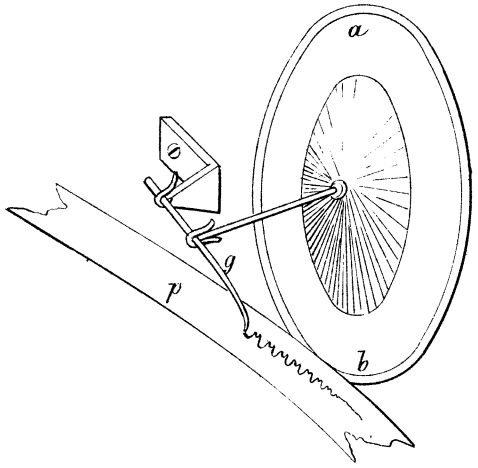


Fig. 3.



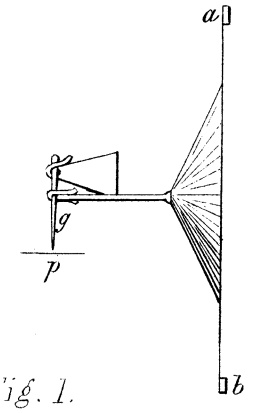
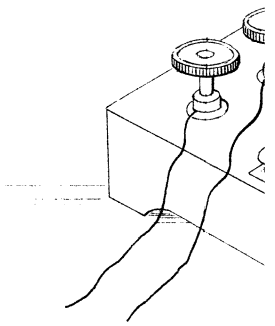


Fig. 1.



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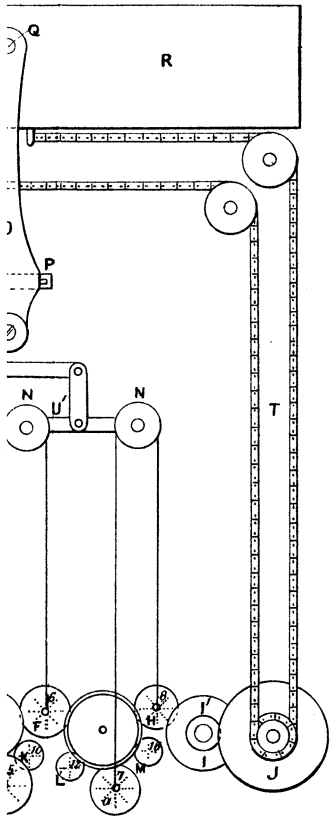

Fig. 3.

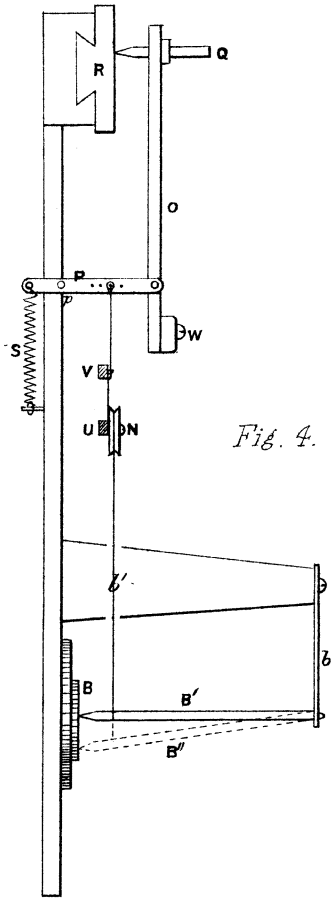

Fig. 4.

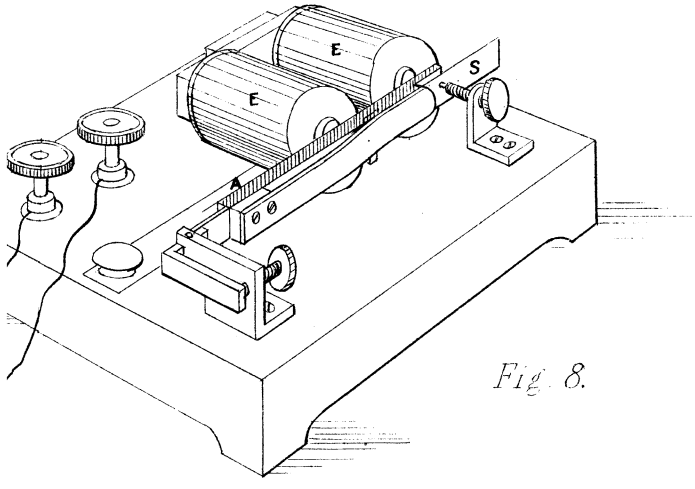

Fig. 8.

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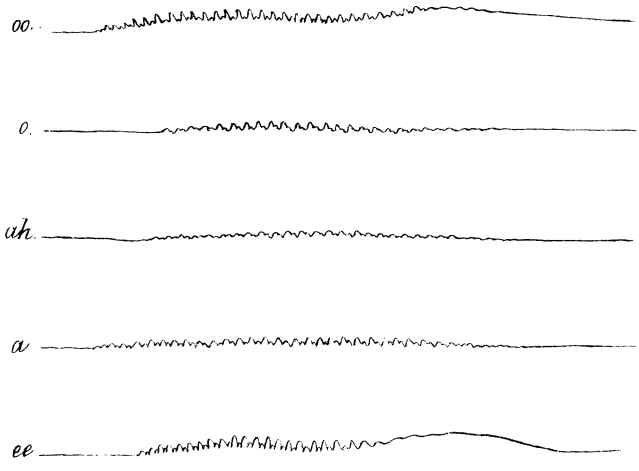
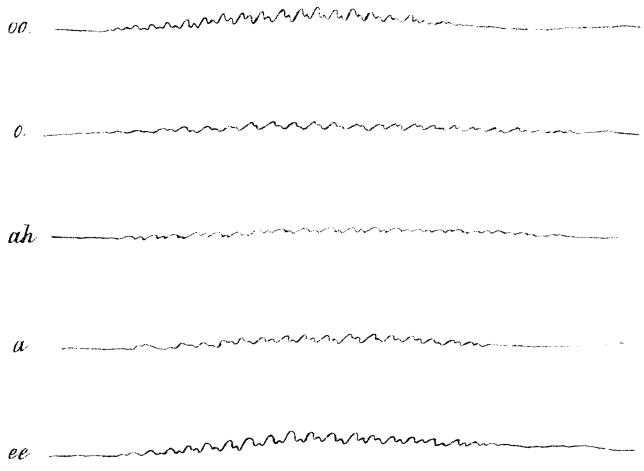


Fig. 2



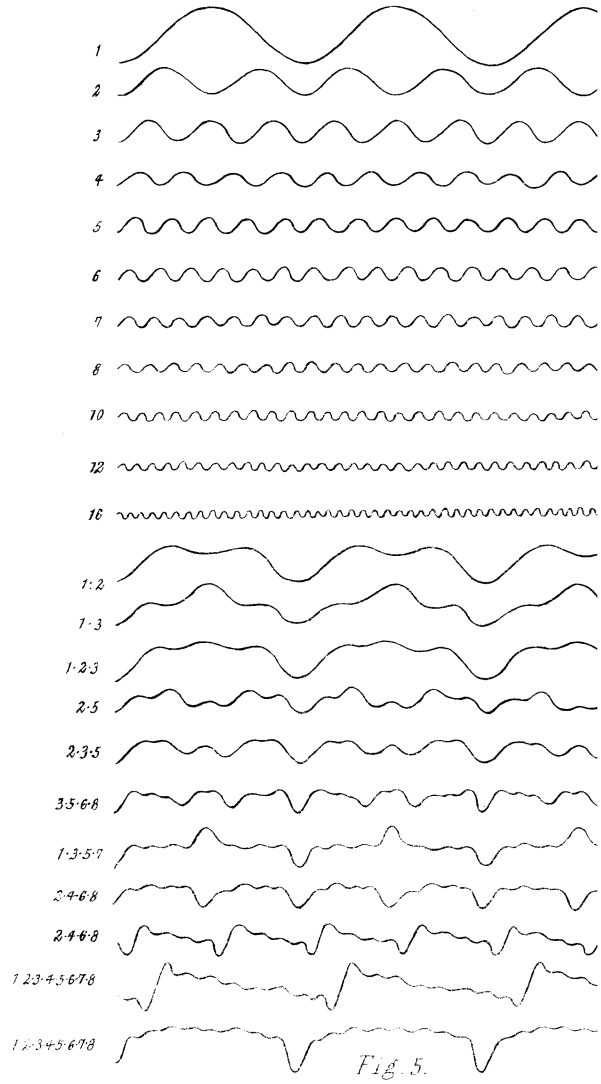


Fig. 5.

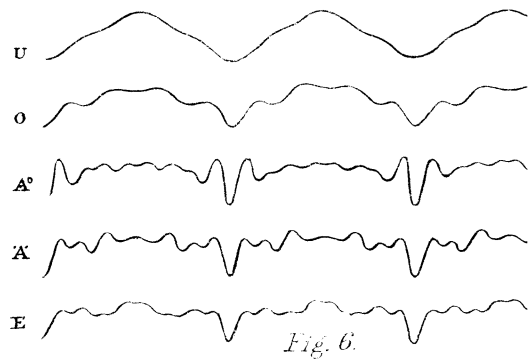


Fig. 6.

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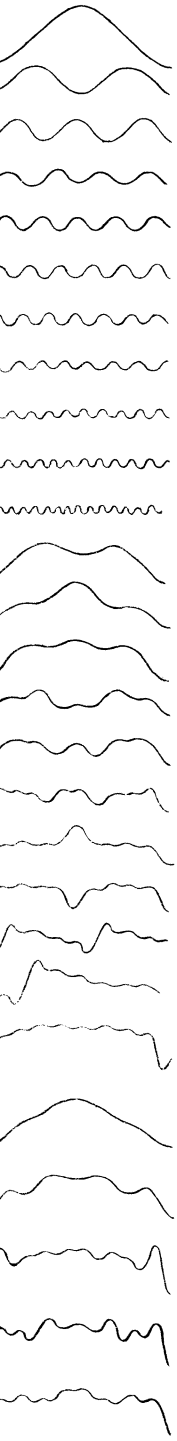


Vowel O.

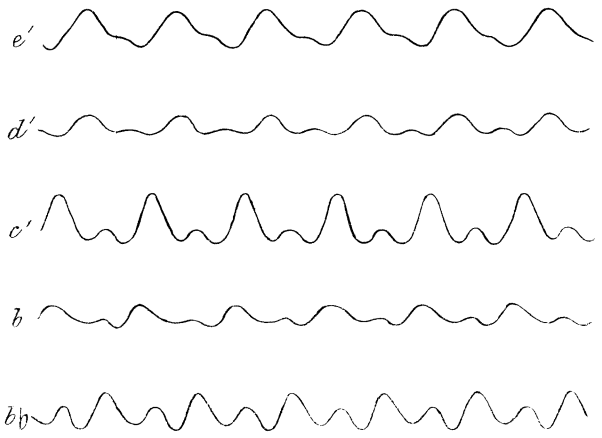


Fig. 7.

Vowel O.

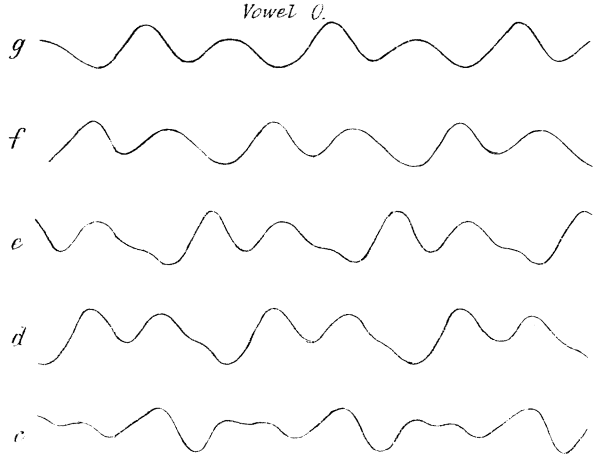


Fig. 7.a

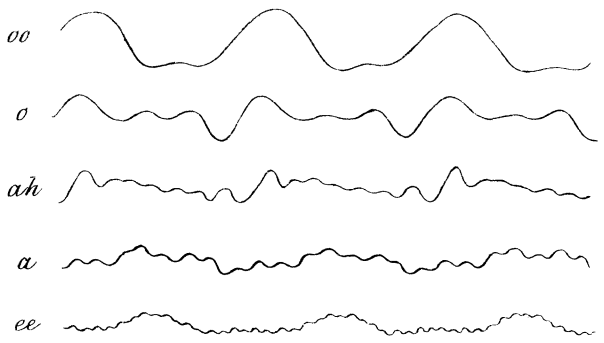
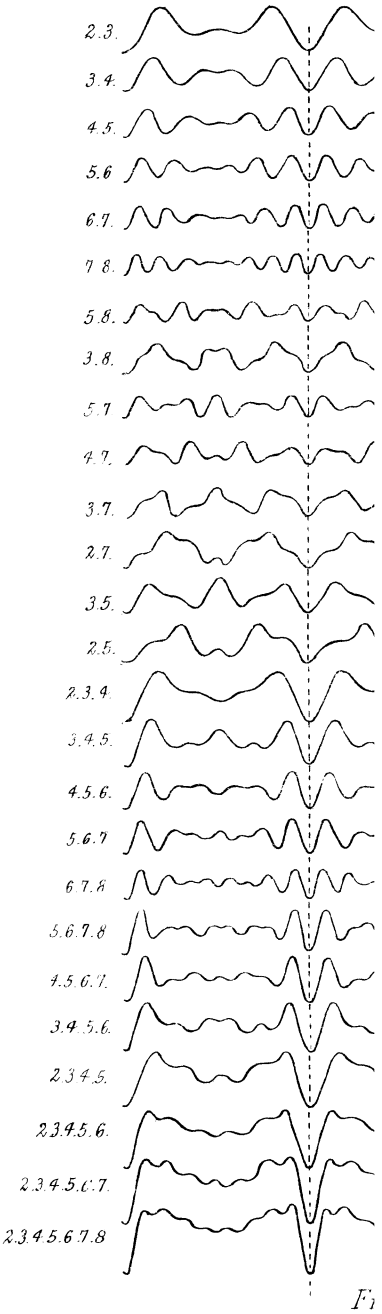


Fig. 10.

Proc.



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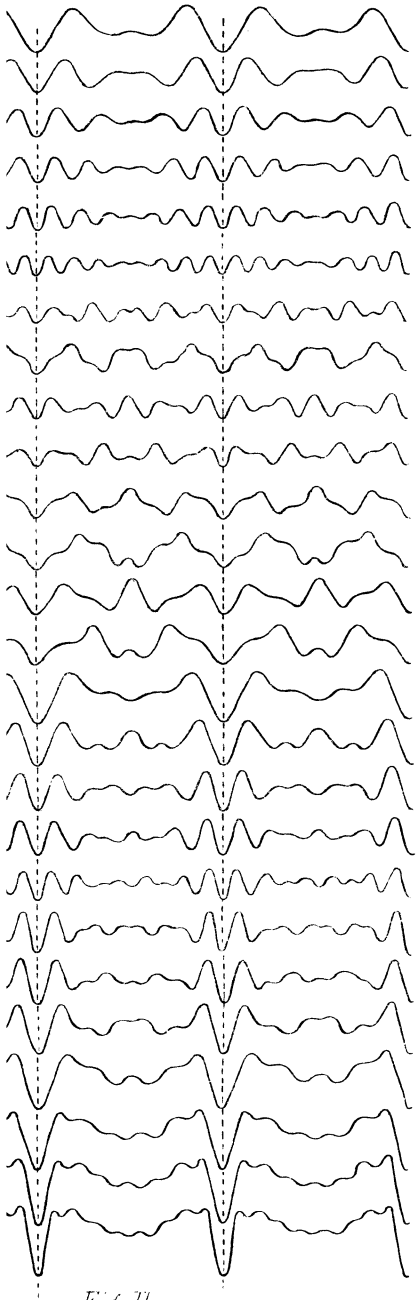


Fig. 11.

The authors are now engaged in pursuing this inquiry into the consonantal sounds.

II. "On the Reversal of the Lines of Metallic Vapours." No. V.

By G. D. Liveing, M.A., Professor of Chemistry, and J. Dewar, M.A., F.R.S., Jacksonian Professor, University of Cambridge. Received February 20, 1879.

Since our last communication we have continued our experiments, using the electric arc as a source of heat, in lime and in carbon crucibles as described before. Success depends on the getting a good stream of vapour in the tubular part of the crucible. This is easily attained in the lime crucibles, which quickly reach a very high temperature, but are very soon destroyed; not so certainly in the carbon crucibles, which are good conductors of heat. The latter, however, last for a very long time.

In our experiments with tubes heated in a furnace we used a small spectroscope with a single prism, which gave a good definition and plenty of light; but in the experiments here described we have used a larger spectroscope by Browning, with two prisms of 60° and one of 45°, taking readings on a graduated circle instead of on a reflected scale.

Both in the lime and in the carbon crucibles we have found that the finely channelled spectrum, extending with great uniformity from end to end, always made its appearance so long as the poles were close together. A few groups of bright lines appear on it. We have not at present investigated this remarkable spectrum further. In several cases we have observed the absorption lines of the metals put into the crucibles on this channelled spectrum as a background, but generally when the vapours in the crucibles become considerable, the channellings give place to a spectrum of bright lines on a much less bright continuous background; we have used generally thirty cells in the galvanic battery, sometimes only twenty-five, once forty.

The calcium line with wave-length 4,226 almost always appears more or less expanded with a dark line in the middle, both in the lime crucibles and in carbon crucibles into which some lime has been introduced; the remaining bright lines of calcium are also frequently seen in the like condition, but sometimes the dark line appears in the middle of K (the more refrangible of Fraunhofer's lines H), when there is none in the middle of H. On throwing some aluminium filings into the crucible, the line 4,226 appears as a broad dark band, and both H and K as well as the two aluminium lines between them appear for a second as dark bands on a continuous background. Soon they appear as bright bands with dark middles; gradually the dark line disappears from H, and afterwards from K,

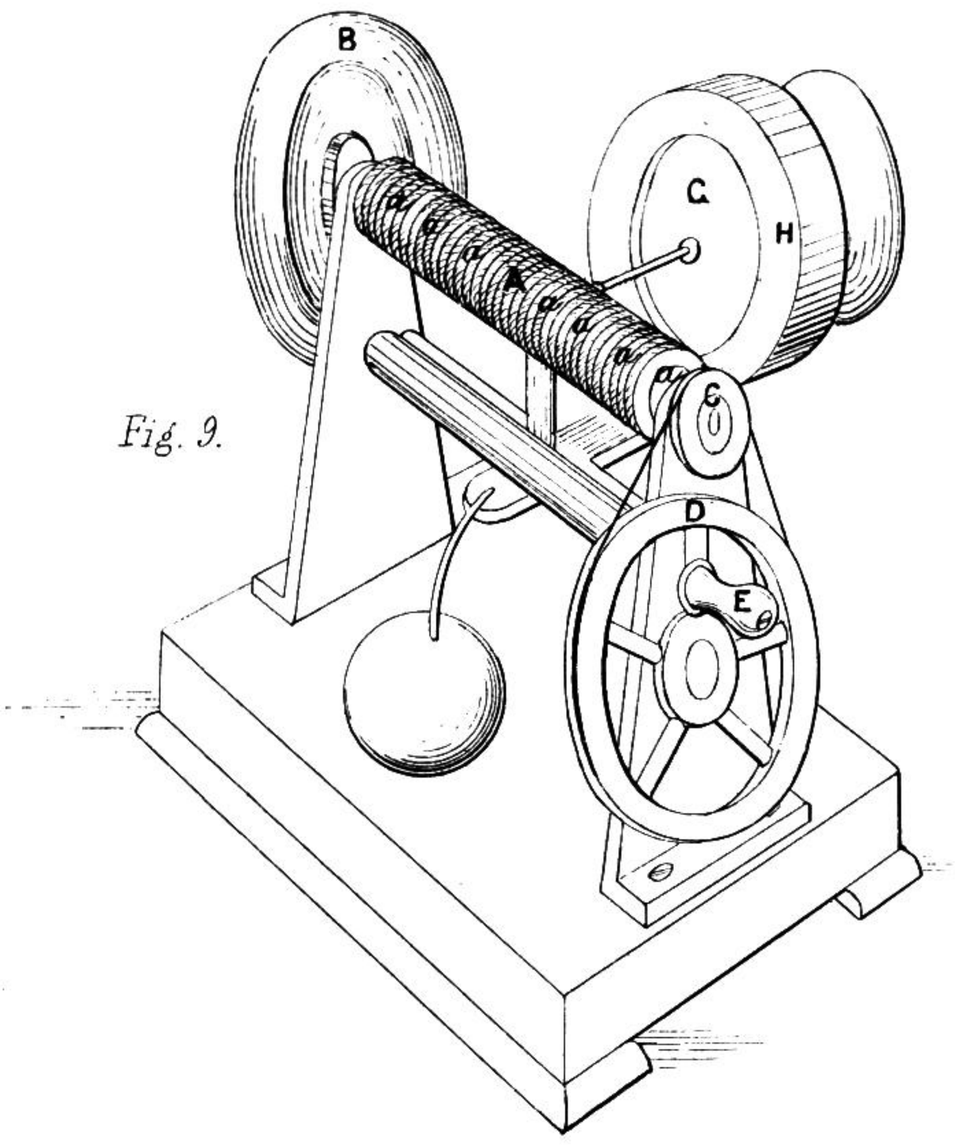


Fig. 9.

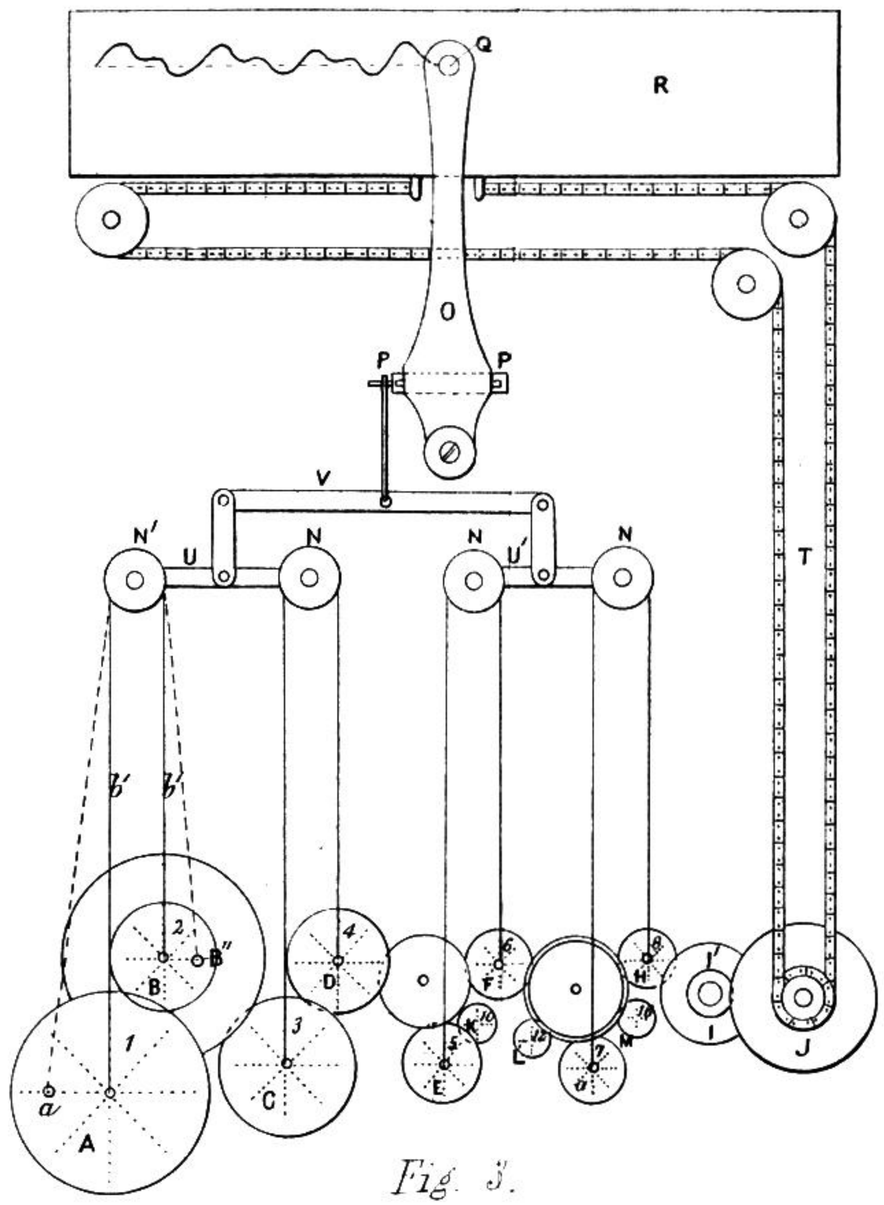


Fig. 3.

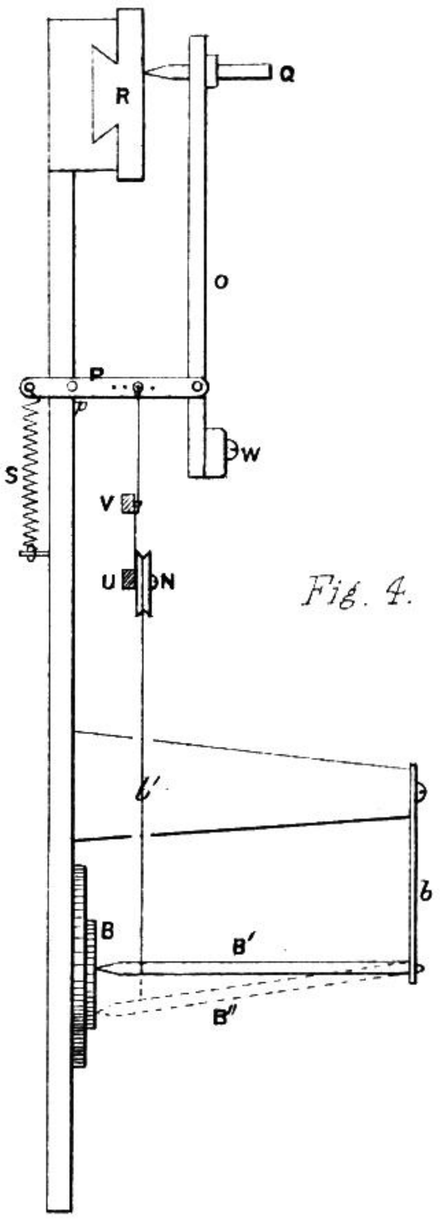
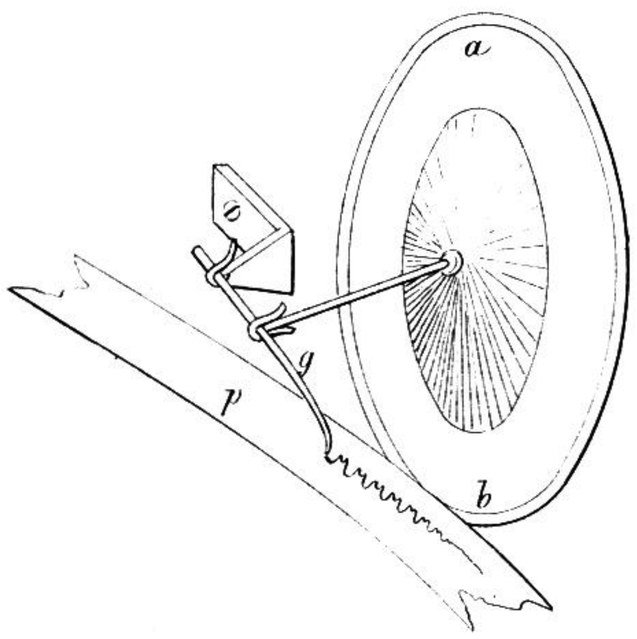


Fig. 4.



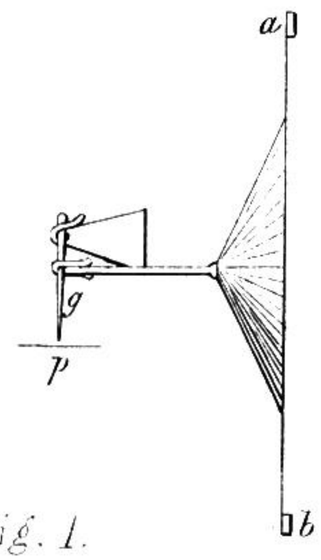


Fig. 1.

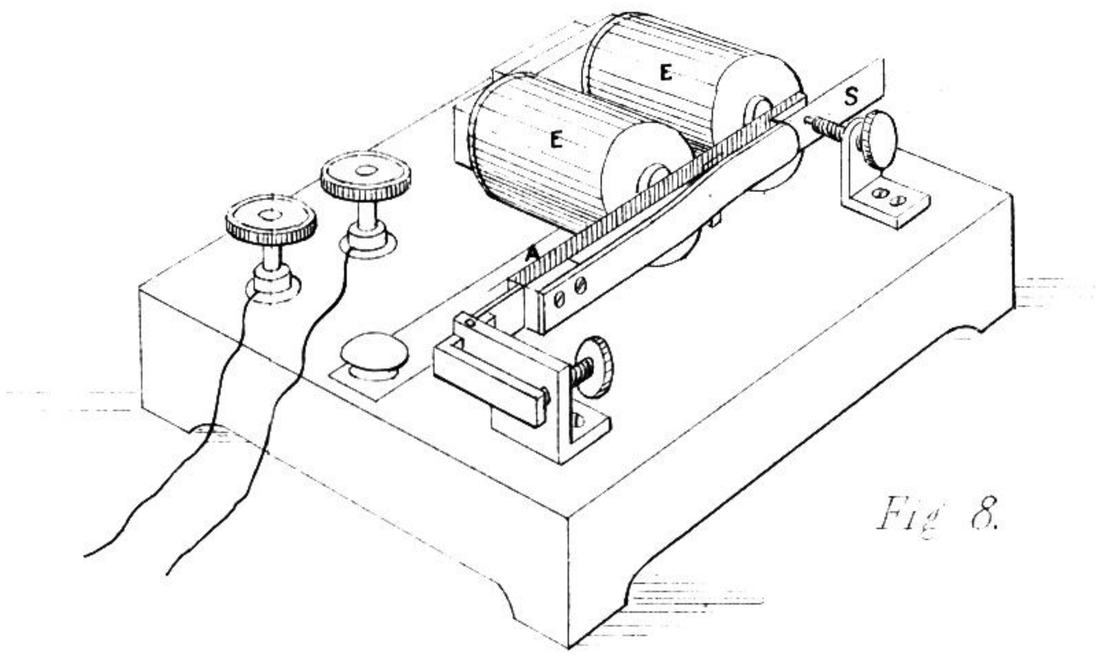


Fig. 8.

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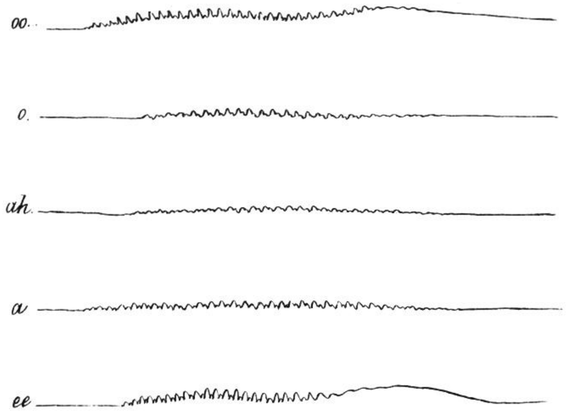
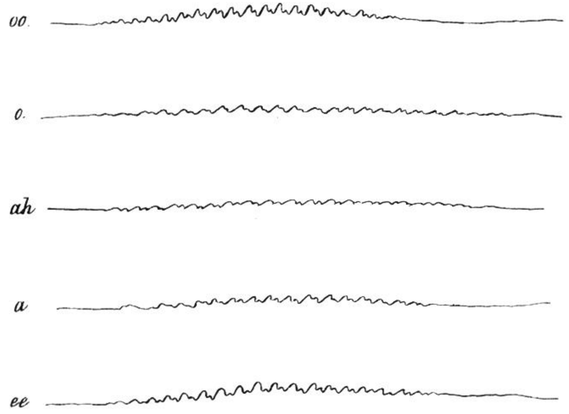


Fig. 2



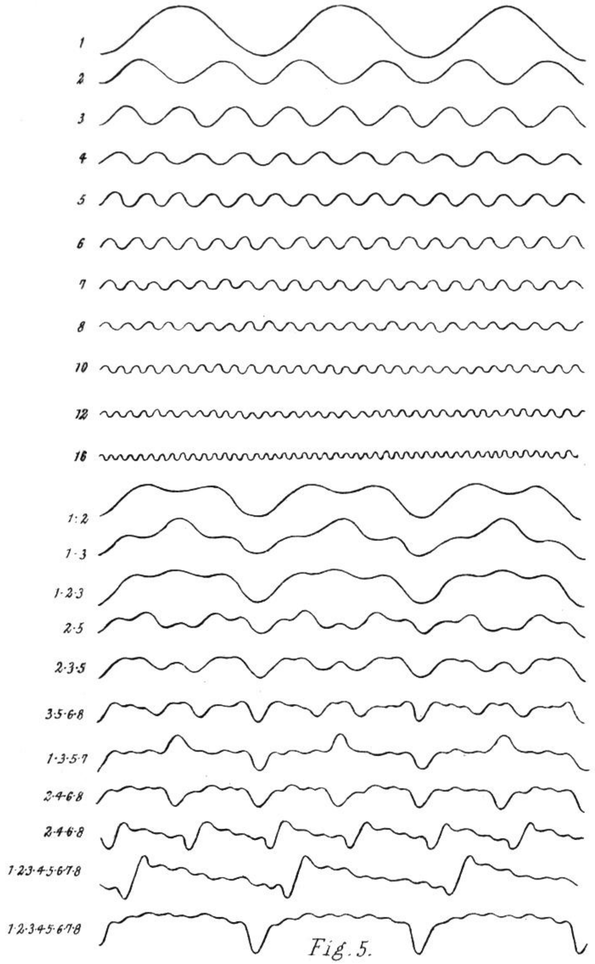


Fig. 5.

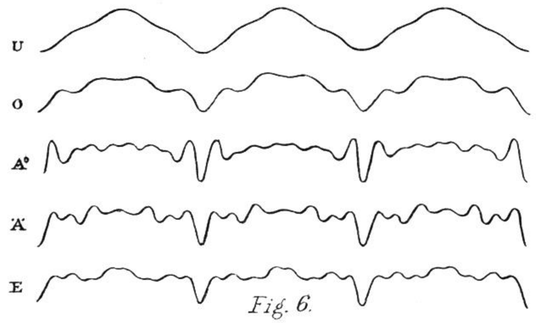


Fig. 6.

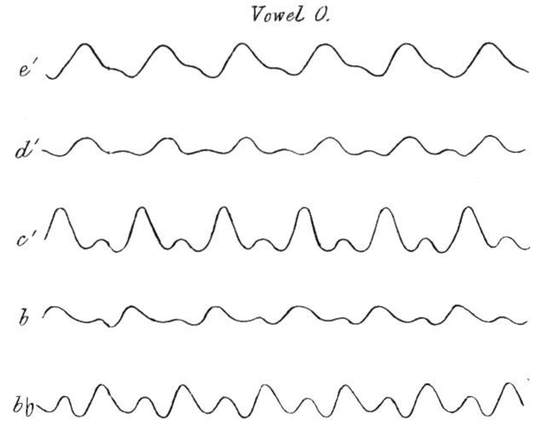


Fig. 7.

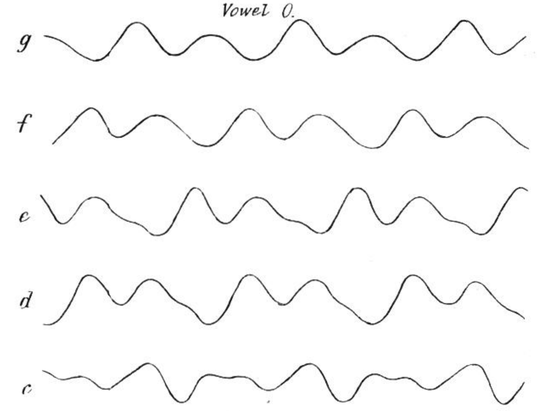


Fig. 7ª

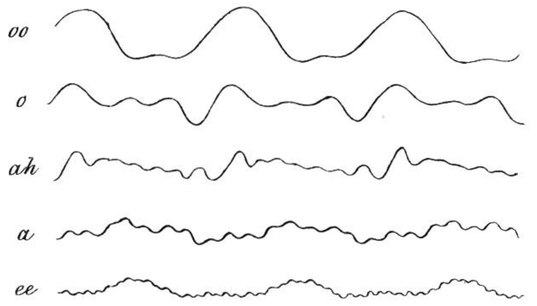


Fig. 10.

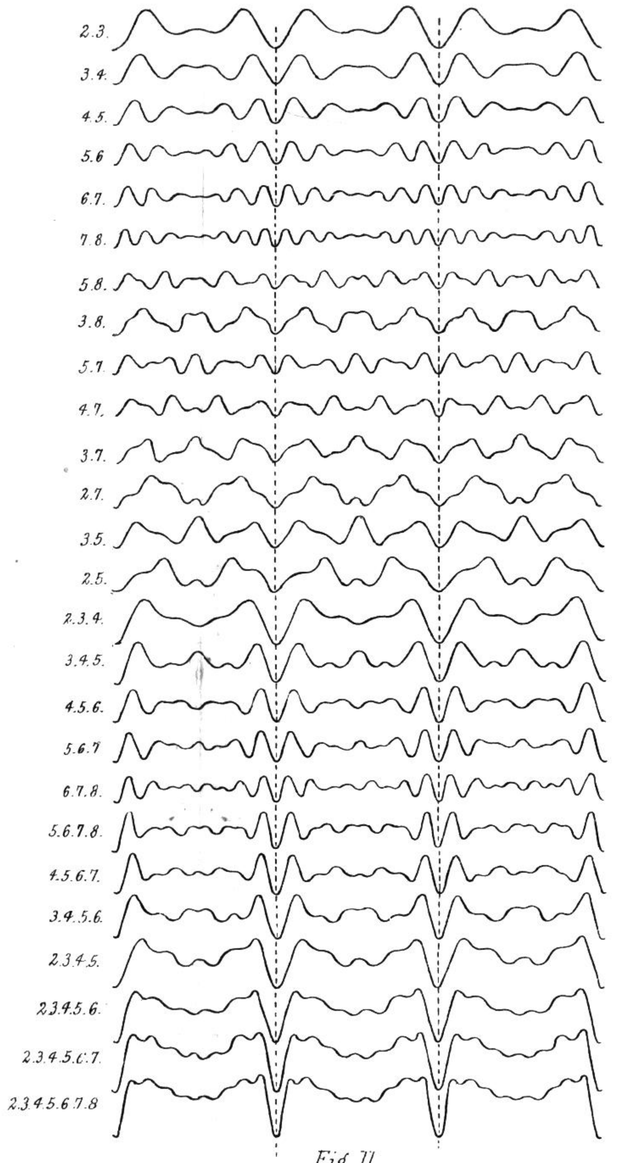


Fig. 11.